

Superhumps in the Rarely Outbursting SU UMa-Type Dwarf Nova, HO Delphini

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Abstract

We observed the 1994, 1996 and 2001 outbursts of HO Del. From the detection of secure superhumps, HO Del is confirmed to be an SU UMa-type dwarf nova with a superhump period of 0.06453(6) d. Based on the recent observations and the past records, the outbursts of HO Del are found to be relatively rare, with the shortest intervals of superoutbursts being ~ 740 d. Among SU UMa-type dwarf novae with similar outburst intervals, the outburst amplitude (~ 5.0 mag) is unusually small. HO Del showed a rather rapid decay of the superhump amplitudes, and no regrowth of the amplitudes during the later stage, in contrast to the commonly observed behavior in SU UMa-type dwarf novae with long outburst intervals. We positively identified HO Del with a ROSAT X-ray source, and obtained a relatively large X-ray luminosity of $10^{31.1 \pm 0.2}$ erg s $^{-1}$. We also performed a literature survey of SU UMa-type dwarf novae, and presented a new set of basic statistics. The SU UMa-type dwarf novae with a brightening trend or with a regrowth of superhumps near the termination of a superoutburst are found to be rather tightly confined in a small region on the (superhump period–supercycle length) plane. These features may provide a better observational distinction for the previously claimed subgroup of dwarf novae (Tremendous Outburst Amplitude Dwarf Novae).

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (HO Delphini) — stars: novae, cataclysmic variables — stars: oscillations

1. Introduction

Dwarf novae (DNe) are a class of cataclysmic variables (CVs), in which the instabilities in the accretion disks cause outbursts (for reviews of dwarf novae, see Osaki 1996). SU UMa-type dwarf novae are a class of DNe, which show superhumps during their long, bright outbursts (superoutbursts) (for basic reviews, see Vogt 1980; Warner 1985; Warner 1995).

SU UMa-type dwarf novae have short orbital periods (P_{orb} usually shorter than 0.1 d), qualifying them as the highly evolved population on the standard evolutionary track of CVs (Rappaport et al. 1982; Rappaport et al. 1983; King 1988; Kolb, Baraffe 1999; King 2000). Some objects have been even suggested to have passed the CV minimum period, at which the thermal time scales of the secondary star (Kelvin-Helmholtz time) become comparable to the mass-transfer time scales (Paczynski 1971; King 1988). After passing this period minimum, the mass-losing secondary stars are believed to become degenerate, and will become CVs with brown-dwarf secondaries

(Howell et al. 1997; Politano et al. 1998; Patterson 1998; Patterson 2001; Politano 2002). Several works have been extensively made to observationally confirm possibility (Ciardi et al. 1998; van Teeseling et al. 1999; Howell, Ciardi 2001; Mennickent et al. 2001; Steeghs et al. 2001; Littlefair et al. 2003). There seems to be a certain degree of emerging evidence that at least some SU UMa-type dwarf novae look like to have brown dwarf secondaries.

These object are also intriguing objects from the standpoint of the disk-instability model for dwarf nova outbursts. Historically, the most extreme member (WZ Sge) was selected as the prototype of a small class of SU UMa-type dwarf novae (WZ Sge-type dwarf novae), which are originally characterized by a long (~ 10 yr) outburst recurrence time and a large (~ 8 mag) outburst amplitude (Bailey 1979c; Downes, Margon 1981; Patterson et al. 1981; O'Donoghue et al. 1991; Kato et al. 2001e). The origin of such powerful outbursts of WZ Sge has still been one of the central problems of dwarf nova accretion disks (Smak 1993; Osaki 1995; Lasota et al. 1995; Warner et al. 1996; Mineshige et al. 1998;

Meyer-Hofmeister et al. 1998; Osaki et al. 2001; Buat-Ménard, Hameury 2002).

From a slightly different standpoint, Howell et al. (1995a) observationally proposed that some DNe with large outburst amplitudes (mostly SU UMa-type dwarf novae) show unusual properties, and called them Tremendous Outburst Amplitude Dwarf Novae (TOADs). Although there exists an argument against this nomenclature (cf. Patterson et al. 1996), these objects are generally considered to represent a borderline population of DNe between the most unusual WZ Sge-type dwarf novae and usual SU UMa-type dwarf novae. The TOADs and WZ Sge-type stars are also known to show extremely low frequency of normal outbursts (Warner 1995). Howell et al. (1995a) and Howell et al. (1995b) reported that the TOADs have unusual properties of their superoutburst, particularly in that the TOADs sometimes show *intermediate* outbursts having properties between full superoutbursts and SU UMa-type normal outbursts, and in that some of the superoutbursts of the TOADs are followed by post-superoutburst rebrightenings. The latter property has been subsequently recognized as a common feature with soft X-ray transients (black-hole transients) (Kuulkers et al. 1996). The most dramatic manifestation of this phenomenon was seen in EG Cnc which showed six successive post-superoutburst rebrightenings (Kato et al. 1997; Matsumoto et al. 1998; Patterson et al. 1998). Howell et al. (1995a) proposed that the unusual properties of the TOADs are a result of low mass-transfer rate and low viscosity in quiescence. This possibility has been tested by several authors to more precisely reproduce the observed properties (Osaki 1995; Osaki et al. 1997; Meyer-Hofmeister et al. 1998; Osaki et al. 2001).

From the observational side, both TOADs and WZ Sge-type dwarf novae are known to (almost exclusively) show lengthening of the superhump period during the superoutburst plateau (Semeniuk et al. 1997b; Nogami et al. 1998a; Kato et al. 1998b; Baba et al. 2000; Kato et al. 2001b; Kato et al. 2001e), whose origin is still poorly understood. Baba et al. (2000) showed that a significant deviation from the linear declining trend and a regrowth of the superhumps during the terminal stage of a superoutburst in V1028 Cyg, whose outburst amplitude is comparable to that of TOADs. These phenomena, although still poorly described or understood, may provide an additional clue for understanding the unusual behavior of the accretion disks in large-amplitude, rarely outbursting SU UMa-type dwarf novae, which are sometimes referred to as TOADs or WZ Sge-type.

HO Delphini (= S 10066) is a dwarf nova discovered by Hoffmeister (1967). Hoffmeister (1967) reported two outburst in 1963 October and 1966 September. Although the object was given the permanent variable star designation (Kukarkin et al. 1968), virtually no observation had been reported until recent years. This lack of observation was partly because of the 1° error in the original discovery report by Hoffmeister (1967). The error was corrected in the third volume of the fourth edition of the GCVS (Kholopov et al. 1985). Downes, Shara (1993) gave a finding chart

and Kato (1999) reported precise coordinates. Munari, Zwitter (1998) recorded relatively strong Balmer and He I emission lines, confirming the CV classification. The He II 4686Å emission line was probably weakly present.

The object has been regularly monitored by the VSNET¹ members since 1994. In spite of the monitoring, only three confirmed outbursts have been recorded (1994 August–September, 1996 August–September, 2001 August–September). The relatively low occurrence of the outbursts is consistent with the initial finding by Hoffmeister (1967).

We observed HO Del during the two outbursts in 1994 and 2001. We also performed several snapshot observations during the 1996 outburst.

2. Observation

The 1994 and 1996 observations were performed using a CCD camera (Thomson TH 7882, 576×384 pixels, on-chip 2×2 binning adopted) attached to the Cassegrain focus of the 60-cm reflector (focal length = 4.8 m) at Ouda Station, Kyoto University (Ohtani et al. 1992). An interference filter was used which had been designed to reproduce the Johnson *V* band. The frames were first corrected for standard de-biasing and flat fielding, and were then processed by a microcomputer-based photometry package developed by one of the authors (TK). The 2001 observations were performed at Nyrölä Observatory using a 40-cm Schmidt–Cassegrain telescope and an unfiltered ST-7E CCD camera. The images were analyzed with the AIP4WIN aperture photometry package. The Ouda observations used GSC 1100.64 (GSC *V* magnitude 12.76) as the comparison star, and GSC 1100.213 (*V* = 13.28) and GSC 1100.98 (*V* = 13.76) as the check stars. The Nyrölä observations used GSC 1100.324 (*V* = 12.16) as the primary comparison star and GSC 1100.213 as the check star. The constancy of the comparison stars during the runs was confirmed by comparisons with the check stars.

Barycentric corrections to the observed times were applied before the following analysis. The log of observations is summarized in table 1.

3. Results

3.1. Course of Outburst

The early stage of the 2001 August–September outburst (as shown in subsection 3.2, both 1994 August–September outburst and 2001 August–September outburst were superoutbursts) was relatively well followed by the VSNET observers. The two superoutbursts in 1996 and 2001 are shown in figure 1. Although the start and the termination of each superoutbursts were not severely constrained, the apparent duration (~ 13 d) is characteristic to that of an ordinary SU UMa-type superoutburst.

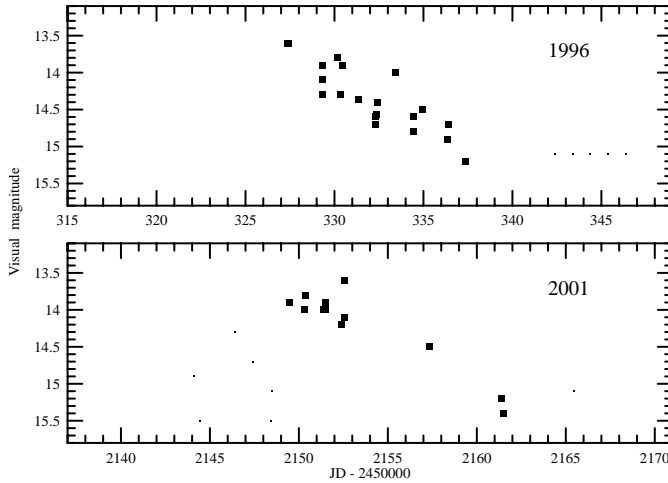
Figure 2 shows the light curve of the 1994 August–September superoutburst. The duration of the outburst

¹ <http://www.kusastro.kyoto-u.ac.jp/vsnet/>

Table 1. Journal of CCD photometry.

	Date		Start–End*	Filter	Exp(s)	N	Mean mag [†]	Error	Obs [‡]
1994	August	26	49591.015–49591.119	V	60	120	1.146	0.005	O
		27	49592.014–49592.219	V	60	141	1.224	0.006	O
		28	49593.065–49593.174	V	90	91	1.412	0.003	O
		29	49594.021–49594.233	V	90	122	1.529	0.003	O
		30	49595.006–49595.217	V	120	59	1.607	0.010	O
		31	49596.184–49596.218	V	120	20	1.565	0.020	O
	September	1	49597.024–49597.240	V	120	99	1.674	0.004	O
		2	49598.137–49598.170	V	120	7	1.843	0.084	O
1996	September	8	50334.972–50334.976	V	90	5	2.132	0.032	O
		15	50341.904–50341.905	V	30	3	3.550	0.585	O
2001	August	28	52150.296–52150.461	none	13	706	2.104	0.004	N

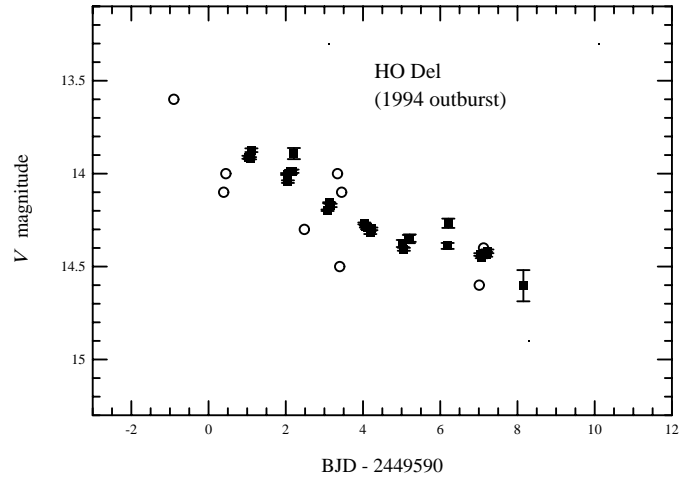
* BJD–2400000.

[†] Differential magnitudes to the comparison star.[‡] O (Ouda), N (Nyrölä)**Fig. 1.** Light curve of the 1996 August–September and 2001 August–September superoutbursts. The large and small dots represent visual positive observations and upper limit observations, respectively, reported to VSNET.

was longer than ~ 10 d. Based on the V -band CCD observations, the object linearly faded at a rate of 0.14 mag d^{-1} between BJD 2449591 and 2449594. This rate is quite characteristic to an SU UMa-type superoutburst plateau (cf. Warner 1985; Patterson et al. 1993; Kato et al. 2002d). The rate of decline became smaller toward the late stage of the superoutburst. The rate reached a minimum of 0.03 mag d^{-1} between BJD 2449595 and 2449597. Such a phenomenon was observed in V1028 Cyg (Baba et al. 2000).

3.2. Superhump Period

Superhumps were clearly present both in 1994 and 2001 observations, clarifying the SU UMa-type nature of HO Del. Figure 3 shows the best representative light curve of the superhumps observed on 2001 August 28. Since the 1994 observations had shorter nightly coverages, we first

**Fig. 2.** Light curve of the 1994 August–September superoutburst. The filled squares with error bars are our V -band CCD observations. The open circles and small dots are visual observations and upper limit observations, respectively, reported to VSNET.

determined an approximate superhump period (P_{SH}) from this longest and highest quality run, and refine the period using the 1994 observation. A period analysis of the 2001 August 28 with the Phase Dispersion Minimization (PDM: Stellingwerf 1978), after removing the linear trend, yielded a period of $0.0642(2)$ d. The error of the period was estimated using the Lafler–Kinman class of methods, as applied by Fernie (1989).

The well-observed portion of the 1994 observation (August 26–29) were analyzed in a similar way, after removing the linear decline trend of the outburst, and corrected for a small nightly deviations from the linear trend. The resultant theta diagram is shown in figure 4. Among the possible one-day aliases, the frequency $15.496 \pm 0.013 \text{ d}^{-1}$, corresponding to $P_{\text{SH}} = 0.06453(6)$ d, is the only acceptable period in comparison with the 2001 observa-

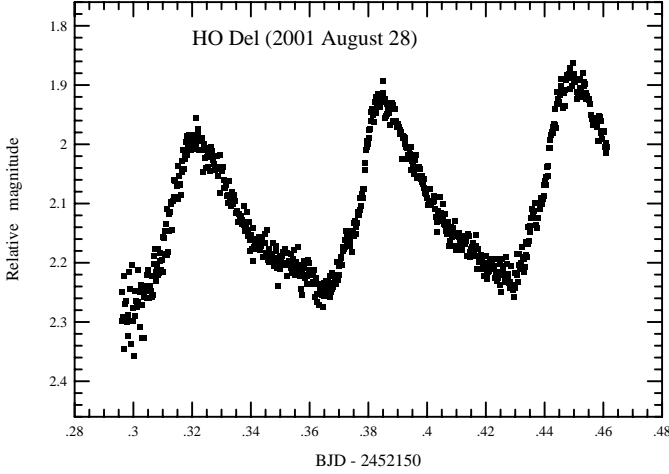


Fig. 3. Superhumps in HO Del observed on 2001 August 28.

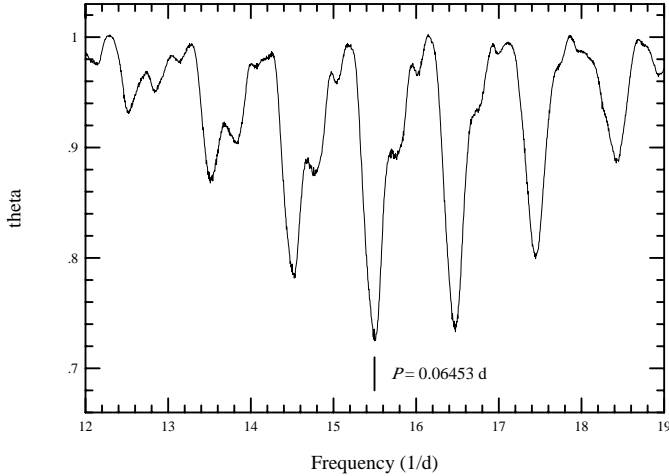


Fig. 4. Phase Dispersion Minimization analysis of the 2001 observation (August 26–29). See text for the selection of the period.

tion. This superhump period supersedes the previously reported preliminary value cited in Nogami et al. (1997b).

4. Superhump Profile

The superhump profile on 2001 August 28 (the observation was performed within 2 d of the outburst rise)², was quite characteristic of fully developed SU UMa-type superhumps (Vogt 1980; Warner 1985). The profiles were, however, different during the 1994 outburst (figure 5).³

² Initial outburst detection was made by M. Reszelski on August 27.972 UT at a visual magnitude of 13.9. The object was not detected in outburst 1 d before this observation. See vsnet-alert 6477, (<http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert6000/msg00477.html>).

³ The start of the 1994 August outburst was not well-constrained. The initial outburst detection was made on 1994 August 24.600 UT at a visual magnitude of 13.6 by M. Moriyama. No observa-

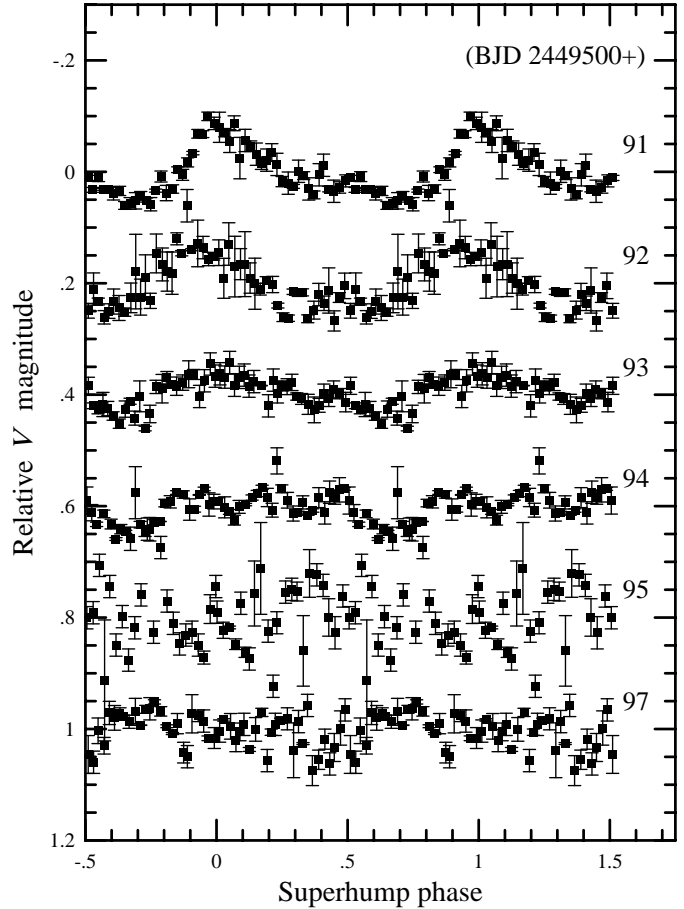


Fig. 5. Nightly averaged hump profiles during the 1994 outburst, folded by $P_{SH} = 0.06453$ d. The phase zero corresponds to BJD 2449591.050. The superhump signal decayed rather rapidly. After BJD 2449594, the superhump signal almost disappeared.

The superhump signal decayed rather rapidly. After BJD 2449594 (1994 August 29, ~ 5 d after the initial outburst detection), the superhump signal almost disappeared.

5. Discussion

5.1. General Properties of Outbursts

In spite of the monitoring by the VSNET members, no confirmed normal outbursts have been recorded between 1994 and 2002. Since the maximum of the superoutbursts reached a magnitude of 13.6, at least some of normal outbursts, which are expected to have maximum magnitude of 14.1–14.6 (Warner 1985), should have been recorded by modern instruments. The lack of such detections seems to suggest that normal outbursts are indeed rare in HO Del. The shortest intervals of the recorded superoutbursts was ~ 740 d. This interval suggests that superoutbursts are also relatively rare, although some of the outbursts or su-

tions were reported for a month preceding this detection. The reported magnitude, however, suggests that the outburst was detected during its relatively early stage.

peroutbursts should have been missed during the unavoidable seasonal gaps. The small number of the recorded outbursts (likely superoutbursts) inferred from the literature (Hoffmeister 1967) also seems to suggest a low outburst frequency.

Among well-observed SU UMa-type dwarf novae, a small number of object have comparable intervals of superoutbursts: UV Per (~ 960 d), VY Aqr (350–800 d), WX Cet (~ 1000 d), SW UMa (459–954 d), V1028 Cyg (380–450 d), V1251 Cyg (~ 1160 d), EF Peg (1000–1400 d, VSNET; Kato et al. 2001e), BC UMa (> 1800 d or ~ 1040 d, Kato et al. 2001e,⁴ DV UMa (~ 770 d, Nogami et al. 2001b), V725 Aql (≥ 1000 d, Uemura et al. 2001). Most of these objects are large-amplitude dwarf novae, sometimes classified as TOADs (Howell et al. 1995a).

Other less well-documented systems with low occurrence of normal outbursts and intervals of superoutbursts likely comparable to HO Del include: PU Per (Kato, Nogami 1995; Kato, Matsumoto 1999b), V844 Her (Kato, Uemura 2000; Thorstensen et al. 2002b), QY Per (Busch et al. 1979; Kato et al. 2000d), V359 Cen (Kato et al. 2002d), and KV Dra (Nogami et al. 2000).

The outburst cycle lengths and the apparently low occurrence of normal outbursts in HO Del seem to share common properties with the so-called TOADs or WZ Sge-type stars, although the outburst amplitude (~ 5.0 mag) is smaller than those of the TOADs or WZ Sge-type stars. If the low outburst occurrence of HO Del is confirmed by future more intensive observations, HO Del may be a rare object with a long outburst cycle length and a rather normal outburst amplitude.

A normal outburst amplitude naturally suggests a normal quiescent luminosity (cf. Warner 1987), which is indicative of a normal mass-transfer rate. In contrast, a long recurrence time would suggest a low mass-transfer rate (Ichikawa, Osaki 1994). If the mass-transfer rate indeed turns out to be normal, the occurrence of outbursts may be somehow suppressed in HO Del.

5.2. Distance, proper motion, and X-ray Luminosity

By applying Warner’s relation (Warner 1987) using the newly established P_{SH} ,⁵ the maximum M_V is expected to be $+5.2$ (see also a discussion in Kato et al. 2002g). An inclination effect (Warner 1986) is likely to be neglected because this star has a low to moderate inclination, as inferred from the lack of eclipses and the single-peaked appearance of the emission lines (Munari, Zwitter 1998). Since Warner’s relation is expected to apply to normal outbursts of SU UMa-type dwarf novae (cf. Kato et al. 2002g; Cannizzo 1998), we use a -0.5 mag

⁴ See also (<http://www.kusastro.kyoto-u.ac.jp/vsnet/DNe/bcuma0302.html>).

⁵ Since the difference between P_{SH} and the orbital period (P_{orb}) is expected to be a few % at this period (Stolz, Schoembs 1984), we can safely use P_{SH} as a substitute for P_{SH} in applying to Warner’s relation. Patterson (1998) listed a likely orbital period without details. Although this period seems to be consistent with P_{SH} , we probably need accurate P_{orb} determination by radial-velocity studies before making a final conclusion on the difference between P_{SH} and P_{orb} .

Table 2. Astrometry of HO Del.

Source	R. A.	Decl.	Epoch
	(J2000.0)		
USNO A2.0	20 36 55.514	+14 03 10.15	1953.682
USNO B1.0	20 36 55.485	+14 03 09.74	1976.0
GSC 2.2.1	20 36 55.498	+14 03 09.46	1990.628

correction to derive an expected maximum M_V for superoutbursts. Using the maximum visual magnitude of 13.6 for the recent superoutbursts, the distance is estimated to be ~ 600 pc. Given the above uncertainties, the error of the distance modulus is expected to be 0.3 mag, which makes a range of the likely distance to be 400–800 pc.

In order to study a possible proper motion, we examined the available astrometric catalogs and the scanned images (Table 2). The errors are typically less than $0''.3$. Although the literal values of declination were slightly different, no distinct proper motion was detected in a comparison of DSS 1 and 2 scans. This indicates that the proper motion of HO Del is smaller than $0''.02 \text{ yr}^{-1}$. USNO B1.0 (Monet et al. 2003) shows zero proper motion for this object. This lack of a detectable proper motion is consistent with the above distance estimate.

HO Del is quite reasonably identified with a ROSAT source 1RXS J203654.3+140301 (Voges et al. 2000), which has a 52–201 keV count rate of $0.030 \text{ count s}^{-1}$. By following the formulation by (Verbunt et al. 1997), we obtain an X-ray luminosity of $10^{31.1 \pm 0.2} \text{ erg s}^{-1}$ (the error includes both errors of the count rate and the distance estimate). Although we will need future different ways of, or an even direct, distance estimates, this value would potentially make HO Del one of the luminous X-ray sources among dwarf novae (Verbunt et al. 1997). This luminosity would suggest that the white dwarf of HO Del may be weakly magnetic, as in intermediate polars (IPs) (Verbunt et al. 1997). If the inner disk is truncated by the magnetized white dwarf in an IP, the apparently low occurrence of outbursts in HO Del (subsection 5.1) may be a result of resulting suppression of the disk instability (Angelini, Verbunt 1989). Although the strength of the quiescent He II emission is not as striking as in other typical intermediate polars, a search for IP-type coherent oscillations would be meaningful.

6. Statistics and Late-Time Superhump Evolution in SU UMa-Type Dwarf Novae

HO Del showed a relatively rapid decay of the superhump amplitudes. A similar phenomenon was observed in V1028 Cyg (Baba et al. 2000) and DM Dra (Kato et al. 2002e). The subsequent behavior was different between HO Del and V1028 Cyg in that no regrowth of the superhumps during the later stage, during which the rate of decline became temporarily slower, was observed in contrast to the V1028 Cyg case (Baba et al. 2000).

Since it has been becoming evident that the regrowth

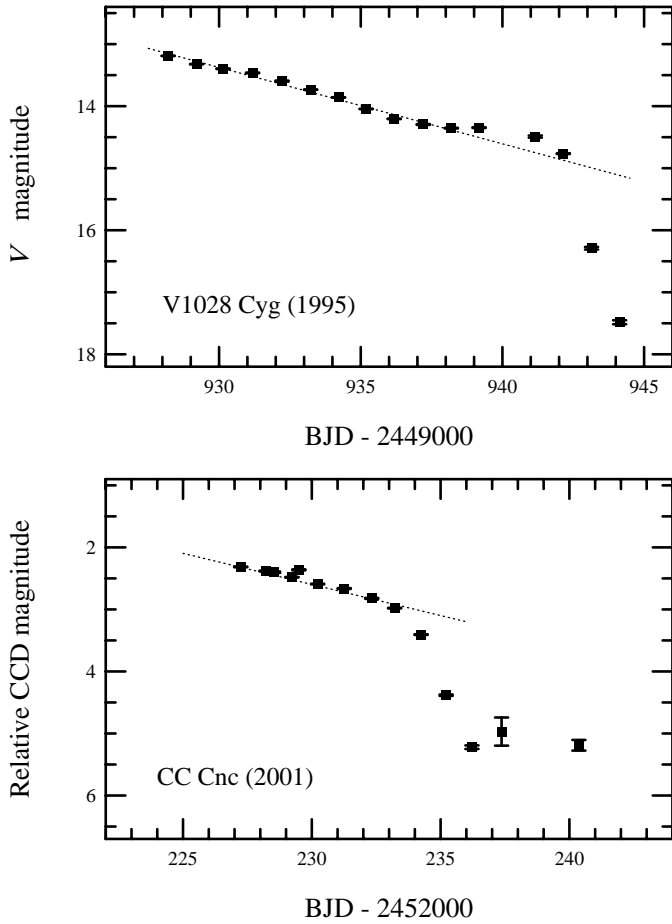


Fig. 6. Brightening trend near the termination of a superoutburst. [Upper: with brightening (V1028 Cyg: data from Baba et al. 2000). Lower: without brightening (CC Cnc: data from Kato et al. (2002f), the first night data were omitted because of a different instrument employed)]. The dashed lines represent linear fits to the earlier stage of the plateau portion. The upward deviation in V1028 Cyg is evident.

of the superhumps is rather commonly seen in SU UMa-type dwarf novae with infrequent outbursts, we performed a literature survey of SU UMa stars in order to see the relation between this phenomenon, as well as the brightening trend near the termination of a superoutburst, and the other parameters. Figure 6 shows a comparison of systems with and without brightening trend near the termination of a superoutburst. Ishioka et al. (2003) also provides a well-recorded presentation of the same phenomenon in HV Vir. Figure 7 shows a representative example of regrowth of superhumps near the termination of a superoutburst (Baba et al. 2000).

The result is presented in table 3. The “Yes” classification in the “Rise” field (brightening near the termination of a superoutburst) generally corresponds to more than 0.1 mag deviation from the linear decline trend. The “Yes” classification in the “Regrowth” field (regrowth of the superhumps during the terminal stage of a superoutburst) corresponds to a detectable regrowth of the superhumps

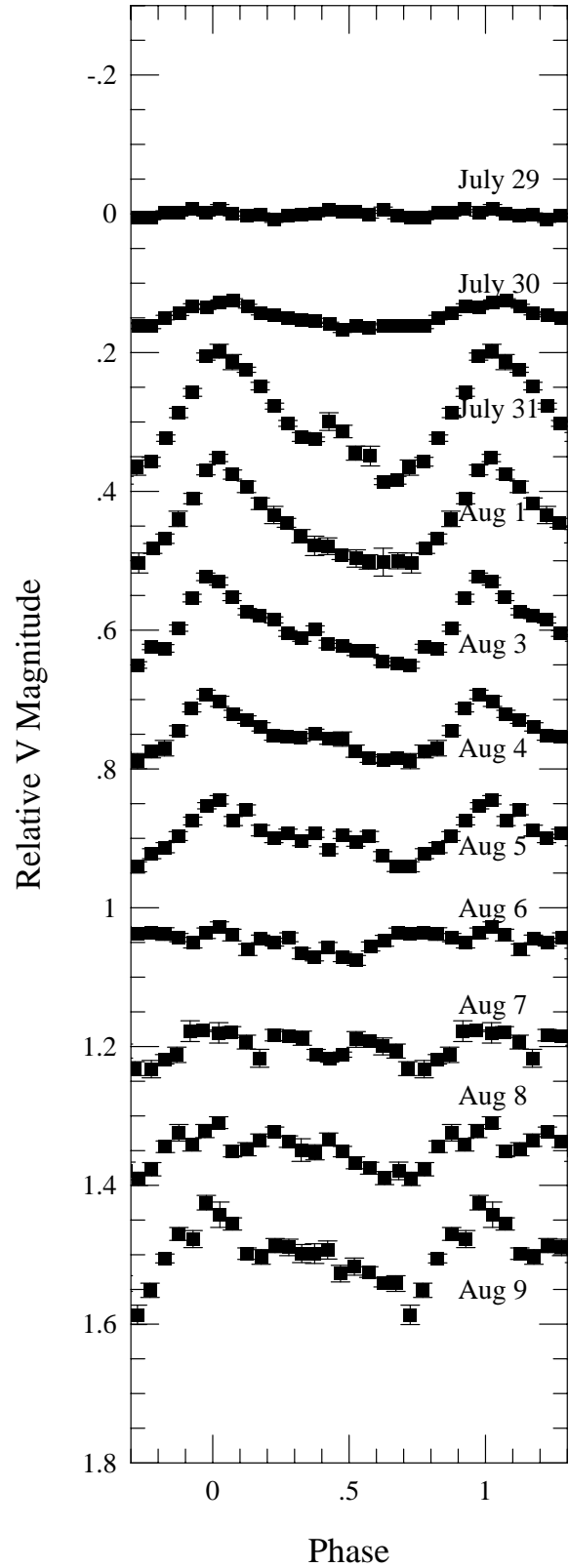


Fig. 7. Example of regrowth of superhumps near the termination of a superoutburst [reproduced from Figure 6 in Baba et al. (2000) by permission].

before the start of the final, rapid decline. A question mark (?) follows if observations did not sufficiently covered the late stages of a superoutburst. Since it is not well-known whether the same star exhibits the same evolution of late-time outburst behavior and superhumps during different superoutbursts, we tried to examine each superoutburst separately whenever possible. In some cases, a combined result from a set of less favorably covered different superoutburst is presented. In the table and the following discussion, we, in principle, used P_{SH} values, which were better determined than P_{orb} values in many systems.

In examining correlations between P_{SH} and other parameters, we predicted the P_{SH} 's of these objects based on the empirical relation (Molnar, Koblunicky 1992).

In ER UMa stars (ER UMa, V1159 Ori, RZ LMi, DI UMa and IX Dra: see Kato, Kunjaya 1995; Nogami et al. 1995c; Kato et al. 1999c), we did not examine the evolution of the superhumps of these objects in the same manner, because there is emerging evidence of unusual superhump evolution at least in one of these systems (Kato et al. 2002b), suggesting that superhumps in ER UMa (and possibly in other ER UMa stars) are different in nature from other SU UMa-type dwarf novae.

So-called helium dwarf novae (CR Boo: Wood et al. 1987; Patterson et al. 1997; Provencal et al. 1997; Kato et al. 2000b; Kato et al. 2001d, V803 Cen: O'Donoghue et al. 1987; O'Donoghue, Kilkenny 1989; Patterson et al. 2000c; Kato et al. 2000c; Kato et al. 2001f, CP Eri: Abbott et al. 1992; Groot et al. 2001, KL Dra: Wood et al. 2002) were not included in this survey, although two unusually short-period, hydrogen rich systems (V485 Cen and EI Psc = 1RXS J232953.9+062814) were included.

The typical superhump period and supercycle length (T_s) are given in the initial line of each object. These data are usually taken from Nogami et al. (1997b), supplemented with new measurements based on the references listed.

6.1. Distribution of Superhump Periods

Since table 3 presents the most up-to-date and complete statistics of SU UMa-type dwarf novae, we first reexamined the basic statistics of SU UMa-type dwarf novae. Figure 8 shows a distribution of the superhump periods (P_{SH}) based on this new material. This figure supersedes the previously published statistics (e.g. Fig. 6 of Kolb, Baraffe 1999). Even with the new samples, a discrepancy still exists between the observed and theoretically predicted distributions. This new statistics confirms the claimed deficiency of the shortest period systems (Kolb, Baraffe 1999; Barker, Kolb 2003).

6.2. Distribution of Supercycles

We reexamined the distribution of supercycles, whose importance has been discussed by a number of authors (Hellier 2001; Nogami 1998; Warner 1995). From the standpoint of the disk-instability theory, this distribution is considered to reflect the distribution of mass-transfer rates (Ichikawa, Osaki 1994).

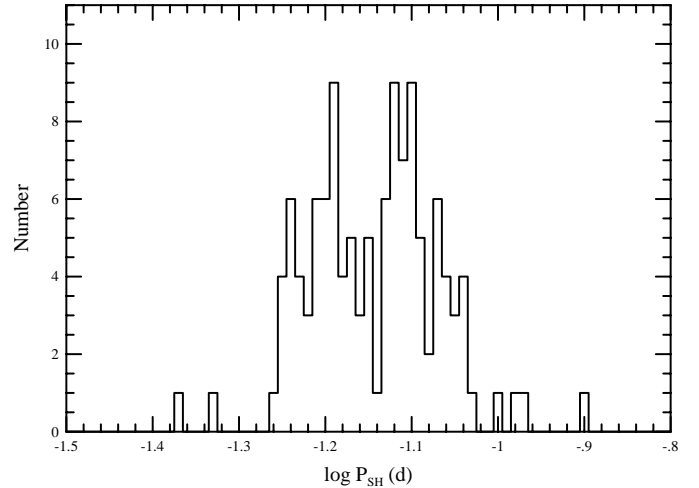


Fig. 8. Distribution of superhump periods (P_{SH}) in SU UMa-type dwarf novae. The data are taken from table 3.

Figure 9 shows the resultant distribution of supercycle lengths in SU UMa-type dwarf novae. When there are different possibilities of supercycle lengths are present, we chose the most likely period. When a range of supercycle lengths is presented, we took a logarithmic mean of the extreme values. When only a lower limit of supercycle lengths is available, we adopted the lower limit as a representative of the supercycle lengths. This figure supersedes Fig. 1 in Hellier (2001), who used Warner 1995. The increase of the number of samples since 1995 is remarkable. Most of SU UMa-type dwarf novae have $2.0 < \log T_s < 3.0$. The objects below $\log T_s < 1.8$ are ER UMa stars, except for Var 73 Dra ($\log T_s \sim 1.78$: Nogami et al. (2003b)), whose relation with the ER UMa stars is still unclear. Despite intensive efforts to search for transitional objects between ER UMa stars and usual SU UMa stars, any attempt has not yet been successful (Kato et al. 2003a). Many of the objects with $\log T_s > 3.5$ are WZ Sge-type stars (Kato et al. 2001e). Although there have been a suggestion that SU UMa-type dwarf novae and WZ Sge-type stars comprise a continuous entity (e.g. Patterson et al. 1996), the most up-to-date seem to illustrate a gap around $\log T_s \sim 3.5$. The reality of the gap needs to be verified by future studies.

Figure 10 shows the relation between P_{SH} and T_s . Although there is a tendency of a slight increase of typical T_s toward shorter P_{SH} , the new statistics revealed that many of SU UMa-type dwarf novae have a fairly typical value of $\log T_s \sim 2.5$ ($T_s \sim 300$ d) regardless of the superhump period (or orbital period). There is, however, a wide-spread distribution of T_s around the period $0.055 \leq P_{\text{SH}} \leq 0.065$ d. The systems with short supercycle lengths ($\log T_s \leq 1.8$) are ER UMa stars, and those with long supercycle lengths ($\log T_s \geq 3.6$) are WZ Sge-type stars.

Although a concentration of these objects around the shortest P_{SH} has been widely discussed (cf. Nogami 1998;

Table 3. Outburst parameters and superhump regrowth in SU UMa-type stars.

Object*	P_{SH}	T_s^\dagger	Rise ‡	Regrowth §	References
V485 Cen (1997)	0.04216	320:	No	No	1
EI Psc (2001)	0.04637	...	No	No	2, 3, 4
DI UMa (1996)	0.05529	25–45	No	ER	5
(1998)			No	...	6
V844 Her (2000+)	0.05592	220–290	Yes?	...	7, 8, 9
V2176 Cyg (1996)	0.0561	>2000	No $^\parallel$	No?	10
V592 Her (1998)	0.056498	4000:	Yes?	Yes?	11, 12
(1968)			Yes?	...	13, 14
UW Tri (1995)	0.0569	4000:	...	...	15
LL And (1993)	0.057006	5000	No?	...	16, 17
WZ Sge (2001)	0.05721	8200–11000	No $^\parallel$	No	18, 19, 20
AL Com (1995)	0.05735	7000	No $^\parallel$	No?	21, 22, 23, 24
MM Hya (2001)	0.05785	380	Yes	...	25
PU CMa (2003+)	0.05789	362–391	No	No?	26, 27, 28
HV Vir (1992)	0.05820	3800	Yes?	...	29, 30
(2001)			Yes	Yes	31
SW UMa (1996)	0.05833	459–954	Yes?	Yes?	32, 33, 34
(2002)			Yes	Yes	35
V1141 Aql (2002)	0.05930	340:	...	...	36, 37
RZ LMi (1995+)	0.05946	19	No	ER	38, 39
WX Cet (1998)	0.05949	1000:	Yes	Yes	40
(1991)			Yes?	Yes?	41
(1989)			Yes?	...	42
KV Dra (2002)	0.06012	840:	Yes	Yes?	43, 44
(2000)			Yes?	...	45, 46
T Leo (1993)	0.0602	420	...	...	47, 48, 49
EG Cnc (1996)	0.06038	7000	No?	No?	50, 51, 52
RX Vol (2003)	0.06117	...	Yes	Yes	53
MM Sco (2002)	0.06136	298–497	...	...	54
V1028 Cyg (1995)	0.06154	380–450	Yes	Yes	55
UZ Boo (1994)	0.0619:	5800?	No?	...	30, 56, 57, 58
V1040 Cen (2002)	0.0622	211	No?	...	59, 60
AQ Eri (1991)	0.06225	300:	...	...	61
CI UMa (1995,2003)	0.06264	140	No?	...	62, 63
XZ Eri (2003)	0.06281	396:	Yes	Yes	64, 65
GO Com (2003)	0.06297	(2900:/N?)	Yes?	No?	66
V402 And (2000,1985)	0.06339	...	Yes?	...	67, 68, 69
CG CMa (1999)	0.0636:	...	Yes?$^\parallel$	...	70, 71
V436 Cen (1978)	0.06383	630	Yes?	...	72, 73
V1159 Ori (1995+)	0.0641	44.6–53.3	No?	ER	39, 74, 75, 76, 77
V2051 Oph (1998)	0.06423	227	No?	No?	78, 79
VY Aqr (1986)	0.0645	350–800?	Yes?	Yes?	80
BC UMa (2000)	0.06452	>1800	...	...	81
HO Del (1994+)	0.06453	740:	Yes	No	82
OY Car (1980)	0.064544	346	Yes?	Yes?	83, 84
(1985)			Yes?	...	85
EK TrA (1985)	0.0649	485	Yes	...	86
1RX J113123+4322.5 (2002)	0.06495	370	Yes?	...	87, 88
TV Crv (1994)	0.0650	390–450	Yes?	Yes?	89
(2001)			Yes	Yes	90

* Year of the outburst in parentheses.

 † Typical supercycle length (d), mainly taken from Nogami et al. (1997b).

The others are estimates from VSNET observations.

 ‡ Brightening near the termination of superoutburst. § Regrowth of the superhumps during the terminal stage of superoutburst.

ER: ER UMa stars, not examined (see text)

 $^\parallel$ Before the “dip” fading in WZ Sge-type dwarf novae.

Table 3. (continued)

Object	P_{SH}	T_s	Rise	Regrowth	References
ER UMa (1995+)	0.06556	43	No?	ER	39, 91, 92
AQ CMi (1996+)	0.06625	410?	...	...	93, 94, 95
UV Per (2001)	0.06641	960	Yes?	Yes?	96
(1989)			...	...	97
CT Hya (1999)	0.06643	280	No?	...	98
(1995)			No?	No?	99
(2000)			No?	No?	100
(2002)			No?	No?	100
IX Dra (2001+)	0.06700	53	No?	ER	101, 102
DM Lyr (1996)	0.0673	250	No?	...	103
(1998)			No?	...	103
AK Cnc (1995)	0.06749	210–390	Yes?	Yes?	104
(1992)			...	...	105
SS UMi (1998)	0.06778	84.7	No	No	106, 107, 108
SX LMi (1994)	0.06850	279	Yes?	No?	109, 110
V701 Tau (1995)	0.0689	380:	...	...	112
V550 Cyg (2000)	0.0689:	...	...	...	113
V1504 Cyg (2001)	0.0690	137	No	...	106, 114, 115
KS UMa (1998,2003)	0.07009	254	No?	...	116, 117, 118
RZ Sge (1996)	0.07042	266	No	No	119
(1994)			No?	No?	120
(1981)			No?	Yes?	121
V1208 Tau (2000)	0.07060	...	No?	No?	122
IR Gem (1982)	0.07076	183	...	...	106, 123
(1991)			...	...	124
TY Psc (2001)	0.0708	210	No?	...	125, 126
CY UMa (1999)	0.07210	300	No?	No?	127
(1995)			No?	No?	128
PU Per (1998)	0.0733	>500	...	...	129
FO And (1994)	0.07411	100–140	No?	No?	106, 130
VW CrB (1997+)	0.0743	240–370	No?	...	131, 132, 133
KV And (1994)	0.07434	240	No?	No?	134
(2002)			No	No?	135
AW Sge (2000)	0.0745	...	...	...	136
NSV 10934 (2003)	0.07478	...	No?	No?	54
V368 Peg (1999,2000)	0.075	390?	No?	No?	137, 138, 139
OU Vir (2003+)	0.07505	410:/N	No?	No?	140, 141, 142
CC Cnc (2001)	0.075518	370	No	No	143
(1996)			No?	...	144
DM Dra (2000,2003)	0.07567	440:	No?	No?	145, 146, 147
VZ Pyx (1996,1998)	0.07568	270	No?	...	148, 149
IY UMa (2000)	0.07588	285.5	No	No	79, 150, 151, 152
(2002)			No	No?	152
AY Lyr (1987)	0.07597	210	No	No	153, 154
(1977)			No	No	155
V1251 Cyg (1991)	0.07604	1160	...	...	156
HT Cas (1985)	0.076077	>450?	...	...	157, 158, 159
QY Per (1999)	0.07681	>1800?	No	No	160
QW Ser (2002)	0.07709	230–276	Yes?	...	161, 162, 163
(2000)			No?	...	161
BE Oct (1996)	0.07711	...	...	...	164

Table 3. (continued)

Object	P_{SH}	T_s	Rise	Regrowth	References
VW Hyi (1972)	0.07714	179	No	No	165
(1974)			No	No	166
(1978)			No	No	167
(1995)			No	No	168
WX Hyi (1977)	0.07737	174	No	No	106, 169
Z Cha (1984+)	0.07740	287	No	No	170, 171, 172, 173
(1987)			No	No	174
TT Boo (1993)	0.07811	245	...	...	175
WY Tri (2001)	0.078483	...	...	...	176, 177
RZ Leo (2000)	0.078529	5800:	Yes	No?	178
V630 Cyg (1996,1999)	0.0789	145->290	No	...	179
SU UMa (1989)	0.07904	160	No	No?	180
V1113 Cyg (1994)	0.0792	189.8	No?	...	181, 182
SDSSp J173008.38+624754.7 (2001)	0.07941	327:	No?	No?	183, 184, 185
AW Gem (1995)	0.07943	300	No?	...	186
CU Vel	0.07999	700-900	...	...	187, 188
DH Aql (2002)	0.08003	300	No	No	189
(1994)			...	...	190
PV Per (1996)	0.0805	180?	...	...	191, 192
HS Vir (1996)	0.08077	186 or 371	No?	No?	193, 194
V359 Cen (2002+)	0.08092	307-397	...	...	65, 195
V660 Her (1999,1995)	0.081	380:	No	...	28, 196, 197, 198
V503 Cyg (1994,1998)	0.08101	89	No	No?	199, 200, 201
BR Lup (1986-2003)	0.08220	140	...	No?	202, 203, 204
NSV 09923 (2003)	0.08253	...	...	...	205
RX Cha (1998)	0.0839	430:	...	...	206, 207
V877 Ara (2002)	0.08411	285-374	No?	No?	27
AB Nor (2002)	0.08438	880:/N	...	...	54
CP Dra (2001+)	0.08474	400?	No?	...	208, 209
V369 Peg (1999)	0.08484	320:	No?	No?	68, 210
TU Crt (1998,2001+)	0.0854	380-530	No?	...	211, 212, 213, 214
HV Aur (1994,2002)	0.08559	...	...	...	215, 216
V589 Her (2002)	0.0864	...	...	...	217
EF Peg (1991)	0.08705	1000-1400	No?	No?	218, 219, 220
(1997)			No?	No?	221
TY PsA (1982,1984)	0.08765	220	No?	No?	222, 223, 224
BF Ara (2002+)	0.08797	84.3	No	No	225, 226, 227
KK Tel (2002)	0.08803	394	...	...	27
V452 Cas (1999)	0.0881	320/N?	No	...	228, 229
DV UMa (1999)	0.08869	770	Yes?	No?	30, 230, 231
(1997)			No?	...	232
V419 Lyr (1999)	0.0901	340:	No?	No?	233, 234
UV Gem (2002)	0.0902	144?	...	...	235, 236, 237
V344 Lyr (1993)	0.09145	109.6	No?	No?	106, 238
YZ Cnc (1978,1988+)	0.09204	134	No	No	155, 239, 240, 241, 242
GX Cas (1994)	0.09297	307	No	No	233, 243
(1999)			No	No	244
V725 Aql (1999)	0.09909	≥ 1000	Yes?	Yes?	245, 246
(1995)			Yes?	Yes?	247
MN Dra (2001-2003)	0.1055	60	No	No?	248, 249
NY Ser (1996+)	0.1064	70-100	No	No	250
TU Men (1980)	0.1262	600?	Yes?	No?	251, 252, 253, 254

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(1998a); 34. Howell et al. (1995b); 35. K. Tanabe et al., in preparation; 36. Olech (2003); 37. VSNET observations; 38. Nogami et al. (1995c); 39. Robertson et al. (1995); 40. Kato et al. (2001b); 41. Kato (1995e); 42. O’Donoghue et al. (1991); 43. M. Uemura et al., vsnet-campaign-dn 2802, 2820; 44. VSNET observations; 45. Nogami et al. (2000); 46. Vanmunster et al. (2000a); 47. Lemm et al. (1993); 48. Kato (1997); 49. Howell et al. (1999); 50. Kato et al. (1997); 51. Matsumoto et al. (1998); 52. Patterson et al. (1998); 53. T. Kato et al., vsnet-campaign-dn 3637,3644; 54. Kato et al. (2003b); 55. Baba et al. (2000); 56. Kuulkers et al. (1996); 57. Richter (1992); 58. Bailey (1979c); 59. B. Monard, private communication, cf. vsnet-alert 7269; 60. VSNET observations; 61. Kato (1991); 62. Nogami, Kato (1997); 63. vsnet-campaign-dn 3588; 64. Uemura et al. (2003); 65. Woudt, Warner (2001); 66. Superhump period variable (e.g. vsnet-campaign-dn 3768). Mean superhump period given; 67. T. Kato et al., vsnet-campaign-dn 170; 68. Antipin (1998a); 69. VSNET observations; 70. Kato et al. (1999b); 71. Duerbeck et al. (1999); 72. Semeniuk (1980); 73. Warner (1975); 74. Patterson et al. (1995); 75. Nogami et al. (1995a); 76. Szkody et al. (1999); 77. Kato (2001e); 78. Kiyota, Kato (1998); 79. Kato et al. (2001g); 80. Patterson et al. (1993); 81. VSNET Collaboration data; 82. this paper; 83. Schoembs (1986); 84. Krzeminski, Vogt (1985); 85. Naylor et al. (1987); 86. Hassall (1985); 87. M. Uemura et al., vsnet-alert 7231; 88. T. Kato and M. Uemura, vsnet-campaign-dn 3540; 89. Howell et al. (1996b); 90. R. Ishioka et al., in preparation; 91. Kato, Kunjaya (1995); 92. Kato et al. (2002b); 93. J. Patterson, vsnet-alert 327; 94. D. Nogami, vsnet-alert 328; 95. VSNET observations; 96. VSNET Collaboration data; 97. Udalski, Pych (1992); 98. Kato et al. (1999a); 99. Nogami et al. (1996); 100. D. Nogami et al., in preparation; 101. Ishioka et al. (2001a); 102. Klose (1995); 103. 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Masi et al., in preparation; other one-day alias is possible; 137. J. Pietz, vsnet-alert 3317; 138. Antipin (1998b); 139. VSNET Collaboration data; 140. T. Kato et al., vsnet-campaign-dn 3656 and VSNET observations; 141. Vanmunster et al. (2000b); 142. Szkody et al. (2002); 143. Kato et al. (2002f); 144. Kato, Nogami (1997b); 145. Kato et al. (2002e); 146. Stepanian (1982); 147. T. Kato et al., vsnet-campaign-dn 3542; 148. Kato, Nogami (1997a); 149. Kiyota (1999); 150. Uemura et al. (2000); 151. Patterson et al. (2000a); 152. M. Uemura et al., in preparation; 153. Udalski, Szymanski (1988); 154. Szymanski, Udalski (1987); 155. Patterson (1979); 156. Kato (1995a); 157. Zhang et al. (1986); 158. Wenzel (1985); 159. Wenzel (1987); 160. Kato et al. (2000d); see also <<http://www.kusastro.kyoto-u.ac.jp/vsnet/DNe/qypr.html>>; 161. D. Nogami et al., in preparation; 162. Kato, Uemura (1999); 163. VSNET observations; 164. J. Kemp and J. Patterson, vsnet-obs 3461; 165. Vogt (1974); 166. Haefner et al. (1979); 167. Schoembs, Vogt (1980); 168. Liller (1996); 169. Bailey (1979b); 170. Warner, O’Donoghue (1988); 171. Warner (1974); 172. Bailey (1979a); 173. Vogt (1982); 174. Kuulkers et al. (1991); 175. Kato (1995d); 176. Vanmunster (2001); 177. M. Uemura et al., vsnet-campaign-dn 376; 178. Ishioka et al. (2001b); affected by beat phenomenon?; 179. Nogami et al. (2001a); 180. Udalski (1990); 181. Kato et al. (1996b); 182. Kato (2001c); 183. M. Uemura et al., vsnet-campaign-dn 1786; 184. T. Vanmunster et al., vsnet-campaign-dn 1792; 185. VSNET observations; 186. Kato (1996b); 187. N. Vogt (1981) Habilitation Thesis, Bochum University, see Mennickent, Diaz (1996); 188. Superhump periods may strongly vary. T. Kato et al. (vsnet-campaign-dn 3136) gives a mean period of 0.08085(3) d from the 2002 December observation; 189. M. Uemura, vsnet-campaign-dn 2699 and VSNET Collaboration data; 190. Nogami, Kato (1995); 191. Vanmunster (1997); 192. VSNET observations; 193. Kato et al. (1998c); 194. Kato et al. (2001h); 195. Kato et al. (2002d); 196. J. Pietz, vsnet-alert 3162; the correct alias selected based on the orbital period in Thorstensen, Fenton (2003); 197. Spogli et al. (1998); 198. VSNET observations; 199. Harvey et al. (1995); 200. Spogli et al. (2000); 201. Kato et al. (2002a); 202. O’Donoghue (1987); 203. Mennickent, Sterken (1998); 204. vsnet-campaign-dn 3584, T. Kato et al., in preparation; 205. T. Kato et al., vsnet-campaign-dn 3821; 206. Kato et al. (2001a); 207. VSNET observations; 208. R. Ishioka et al., in preparation, cf. vsnet-campaign-dn 556; 209. Kolotovkina (1979); 210. Kato, Uemura (2001a); 211. Mennickent et al. (1998); 212. R. Ishioka et al., in preparation; 213. Wenzel (1993); 214. Hazen (1993); 215. Nogami et al. (1995b); 216. T. Kato et al., vsnet-campaign-dn 3061; 217. T. Vanmunster, vsnet-alert 7279; other possible period 0.0950 d; 218. Kato (2002); 219. Howell et al. (1993); 220. VSNET observations; 221. K. Matsumoto et al., in preparation; 222. Barwig et al. (1982); 223. Warner et al. (1989); 224. VSNET observations; 225. Kato et al. (2003a); 226. Kato et al. (2001i); 227. Bruch (1983); 228. T. Vanmunster and B. Fried, vsnet-alert 3707; 229. M. Uemura et al., vsnet-alert 3711; 230. Patterson et al. (2000b); 231. M. Uemura et al., in preparation; see also <<http://www.kusastro.kyoto-u.ac.jp/vsnet/DNe/dvuma9912.html>>; 232. Nogami et al. (2001b); 233. Nogami et al. (1998c); 234. M. Uemura et al., in preparation; see also vsnet-alert 3401; 235. T. Vanmunster, vsnet-alert 7284; 236. Kato, Uemura (2001b); 237. VSNET observations; 238. Kato (1993); 239. van Paradijs et al. (1994); 240. Kato (2001b); 241. Moffett, Barnes (1974); 242. Szkody, Mattei (1984); 243. VSNET observations; 244. M. Uemura et al., in preparation; 245. Uemura et al. (2001); 246. Hazen (1996); 247. Nogami et al. (1995d); the terminal portion of the superoutburst was observed; a large-amplitude superhump-like signal likely indicated a regrowth of the superhumps; 248. Antipin, Pavlenko (2002); 249. Nogami et al. (2003b); the superhump period listed in the table is an average of the two different superoutbursts in Nogami et al. (2003b); 250. Nogami et al. (1998b); 251. Stolz, Schoembs (1984); 252. Stolz, Schoembs (1981b); 253. Stolz, Schoembs (1981a); 254. VSNET observations. Outbursts with intermediate lengths are known; a typical recurrence time of long outbursts is given.

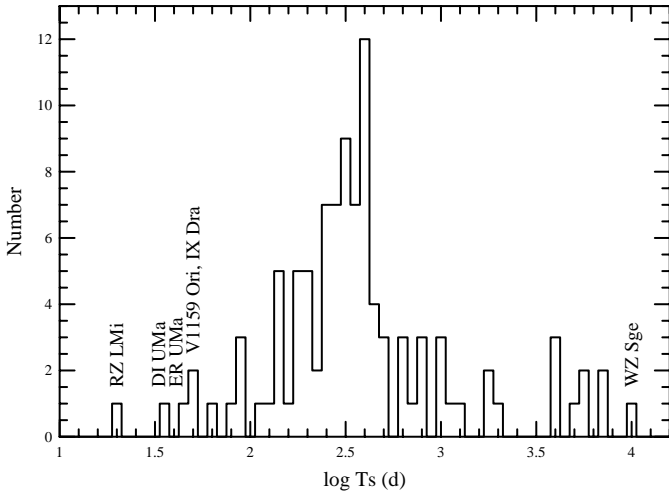


Fig. 9. Distribution of supercycle lengths (T_s) in SU UMa-type dwarf novae. The data are taken from table 3.

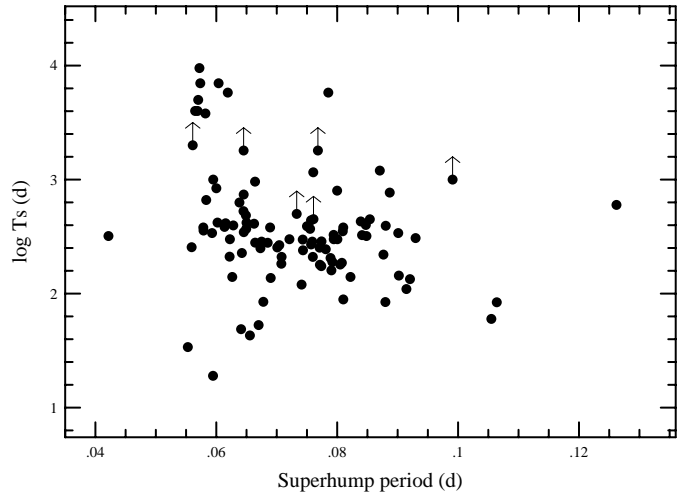


Fig. 10. Relation between P_{SH} and T_s . The data are taken from table 3. The arrows represent lower limits of T_s 's.

Warner 1998; Hellier 2001), the present study more clearly illustrated the segregation between these populations. A previously proposed picture of a continuous entity between usual SU UMa-type dwarf novae and WZ Sge stars (cf. Nogami et al. 1996; Baba et al. 2000) seems to have become less concrete. There are also a small number of objects with long T_s and long P_{SH} , whose existence was not clear in the past studies. One of these objects (RZ Leo) has been studied thoroughly (Mennickent, Diaz 2002; Ishioka et al. 2001b), and has been shown to have a normal lower main-sequence secondary, rather than a brown dwarf. The expected low mass-transfer rate in such a system should therefore be understood as a result of a wide variety of systems even below the period gap. On the other hand, extremely short T_s systems seem to be concentrated in the short P_{SH} range, supporting the earlier finding.

6.3. Brightening near Termination of Superoutburst Plateau

We first inspected the objects with multiple superoutburst observations in order to check the possible variation of the brightening feature near the termination of a superoutburst plateau. Table 4 shows the summary. This result indicates that whether or not there is a brightening feature near the termination of a superoutburst plateau is primarily dependent on the object, rather than individual superoutbursts. DV UMa and QW Ser are the only examples among the well-observed objects which probably showed different types of superoutbursts. These objects apparently need further full-superoutburst observations on every possible occasions.

Figure 11 shows a distribution of objects with or without brightening near the termination of the superoutbursts. The open and filled circles represent no brightening and with brightening (No/No? and Yes/Yes? in table 3), respectively, including suspicious cases. (DV UMa

Table 4. Brightening near Termination of Superoutburst Plateau in Different Superoutbursts.

Object	P_{SH}	Number of superoutbursts with/without brightening	
		Yes	No
V592 Her	0.056498	2	0
WX Cet	0.05949	3	0
KV Dra	0.060005	2	0
OY Car	0.064544	2	0
TV Crv	0.0650	2	0
CT Hya	0.06643	0	4
DM Lyr	0.0673	0	2
RZ Sge	0.07042	0	3
CY UMa	0.07210	0	2
KV And	0.07434	0	2
CC Cnc	0.075518	0	2
IY UMa	0.07588	0	2
AY Lyr	0.07597	0	2
QW Ser	0.07709	1	1
VW Hyi	0.07714	0	4
Z Cha	0.07740	0	2
EF Peg	0.08705	0	2
DV UMa	0.08869	1	1
GX Cas	0.09297	0	2
V725 Aql	0.09909	2	0

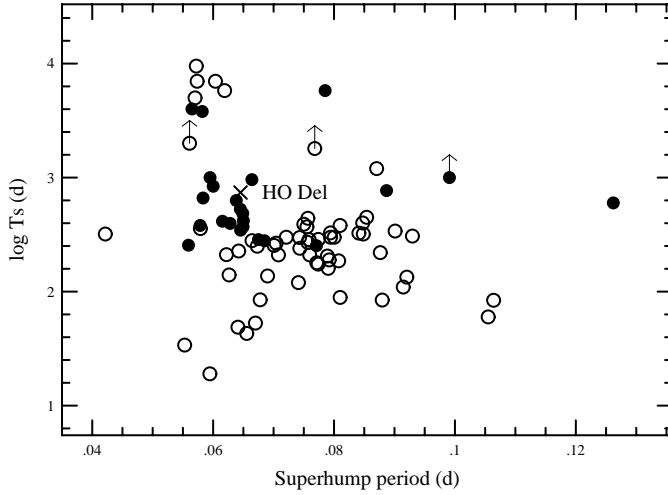


Fig. 11. Brightening near the termination of the superoutbursts. The open and filled circles represent no brightening and with brightening (No/No? and Yes/Yes? in table 3), respectively, including suspicious cases. The arrows represent lower limits of T_s . The location of HO Del (with brightening) is marked with a cross.

and QW Ser were included as systems “with brightening”). There is a strong concentration of systems with brightening in short P_{SH} and long T_s systems, although WZ Sge-type stars usually do not show this type of brightening. Several long- P_{SH} systems showing brightening are clearly confined to the long T_s region. The location of HO Del (with brightening) is consistent with the general tendency.

6.4. Regrowth of Superhumps

We inspected the objects with multiple superoutburst observations in order to check the possible variation of the superhump regrowth near the termination of a superoutburst plateau. Table 5 shows the summary. The symbols are as in table 4. As in brightening feature near the termination of a superoutburst plateau, the existence of the superhump regrowth is primarily dependent on the object, rather than individual superoutbursts. RZ Sge is a possible exception which showed both types of superoutbursts.

Figure 12 shows distribution of objects with or without superhump regrowth near the termination of the superoutbursts. The symbols are the same as in figure 11. A stronger preference of short- P_{SH} systems, than in figure 11, is apparent, although the location of the objects with superhump regrowth nearly overlaps the location of the objects with brightening. This figure suggests that the appearance of superhump regrowth and brightening near the termination of the superoutbursts is phenomenologically coupled. This statistical finding may comprise another aspect of positive correlations between brightening and superhump regrowth, which was claimed by Baba et al. (2000) based on the analysis of the 1995 superoutburst of V1028 Cyg.

The location of HO Del is unusual in its apparent ab-

Table 5. Regrowth of Superhumps in Different Superoutbursts.

Object	P_{SH}	Number of superoutbursts with/without regrowth	
		Yes	No
SW UMa	0.05833	2	0
WX Cet	0.05949	2	0
TV Crv	0.0650	2	0
CT Hya	0.06643	0	3
RZ Sge	0.07042	1	2
CY UMa	0.07210	0	2
KV And	0.07434	0	2
IY UMa	0.07588	0	2
AY Lyr	0.07597	0	2
VW Hyi	0.07714	0	4
Z Cha	0.07740	0	2
EF Peg	0.08705	0	2
GX Cas	0.09297	0	2
V725 Aql	0.09909	2	0

sence of the superhump regrowth. This deviation from the general trend may be related to a rather low (~ 5.0 mag) outburst amplitude of HO Del for a long T_s object. If this is the case, the conditions necessary to manifest the unusual large-amplitude outbursts in some rarely outbursting SU UMa-type dwarf novae, may be somehow responsible for producing the late-time regrowth the superhumps.

We do not discuss whether this argument can be observationally extended to the most extreme WZ Sge-type dwarf novae, which may be a natural extension of so-called TOADs, while recent theoretical interpretations seem to prefer a different entity (Osaki, Meyer 2002; Osaki, Meyer 2003), in which a 1:2 resonance is claimed to be essential for the manifestation of their unusual outbursts. The exclusion of WZ Sge-type dwarf novae from figure 12 may be an artificial result our examination of these phenomena (regrowth of superhumps and brightening) restricted to pre-“dip” observations of WZ Sge-type superoutbursts. If we consider that the rebrightening stage of WZ Sge-type superoutbursts actually corresponds to the late stage of SU UMa-type superoutbursts discussed in this study, it may be possible both WZ Sge-type rebrightenings and late stage brightening (and possibly regrowth of superhumps) have the same underlying mechanism. We leave this an observational open question, partly because individual WZ Sge-type rebrightenings show a wide variety [at least some of which bear more resemblance to normal outbursts (e.g. Kato et al. 1997; Patterson et al. 1998), while some of them even look like a double superoutburst (Nogami et al. 1997a)], and partly because observations are insufficient in most WZ Sge-type stars to judge whether there was a regrowth of superhumps during such a stage.

Although the original TOAD classification has been shown to represent a rather loosely defined class of objects,

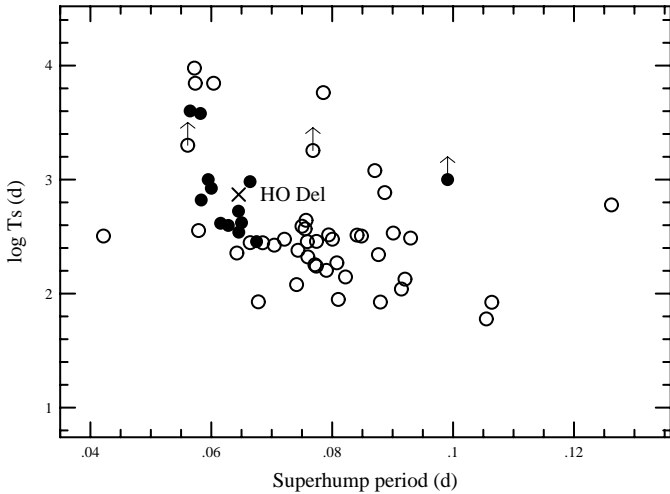


Fig. 12. Regrowth of superhumps near the termination of the superoutbursts. The open and filled circles represent no regrowth and with regrowth (No/No? and Yes/Yes? in table 3), respectively, including suspicious cases. The arrows represent lower limits of T_s . The location of HO Del (without regrowth) is marked with a cross.

the presently discussed features may provide a better observational distinction for SU UMa-type dwarf novae with unusual characteristics.

7. Summary

We photometrically observed the 1994, 1996 and 2001 outbursts of HO Del. From the detection of secure superhumps, HO Del is confirmed to be an SU UMa-type dwarf nova with a superhump period of 0.06453(6) d. Based on the recent observations and the past records, the outbursts of HO Del are found to be relatively rare, with the shortest intervals of superoutbursts being ~ 740 d.

We also performed a literature survey of SU UMa-type dwarf novae, and presented a new set of basic statistics. This new statistics revealed that many of SU UMa-type dwarf novae have a fairly typical value of supercycle lengths of ~ 300 d regardless of the superhump period. There is, however, a wide-spread distribution of T_s around the period $0.055 \leq P_{SH} \leq 0.065$ d. A previously proposed picture of a continuous entity between usual SU UMa-type dwarf novae and WZ Sge stars seems to have become less concrete.

The SU UMa-type dwarf novae with a brightening trend or with a regrowth of superhumps near the termination of a superoutburst are found to be rather tightly confined in a small region on the (superhump period-supercycle length) plane. These characteristics seem to provide better criteria for a small, rather unusual population of SU UMa-type dwarf novae, which likely correspond to, and would better define, the objects previously selected by outburst amplitudes (Tremendous Outburst Amplitude Dwarf Novae). HO Del is rather unusual in that it is located in this region while it did not show regrowth of

superhumps.

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